【 ORIGINAL ARTICLE 】

Validity of "One-size-fits-all" Approaches for the National Health Screening and Education Program: A Large-scale Cohort Study of Corporate Insurance Beneficiaries

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Abstract:
Objective Metabolic syndrome represents a unified condition of atherosclerotic diseases caused by abdominal obesity. The aims of this study were to examine the applicability of the prevalent fixed cut-off values of the abdominal circumference (AC) and body mass index (BMI) to age and gender groups and to identify suitable lifestyle modification factors.
Methods We defined an outcome as having ≥ 2 risk components that are necessary to diagnose metabolic syndrome and examined the cross-sectional association of the AC and BMI with the outcome. We also assessed the effects of time-updated lifestyle information on metabolic traits using longitudinal data.
Patients We enrolled 22,953 beneficiaries of a corporate health insurance scheme who underwent annual health examinations between January 2004 and December 2014.
Results The AC [per 5-cm increase, odds ratio (OR) 1.17, 95% confidence interval (CI) 1.12-1.24] and BMI (OR 1.10, 95% CI 1.07-1.13) were significantly associated with the outcome, adjusted for age, gender, current smoking status, drinking habits, and other lifestyle information. The association between the outcome and AC was modified by gender (p for interaction = 0.033), and the association between the outcome and BMI was modified by age group (p for interaction = 0.049). In the longitudinal analysis, current smoking, drinking habits, and unhealthy eating habits were associated with an increased AC and BMI, whereas regular physical activity was associated with a decreased AC and BMI.
Conclusion We showed that the association between the AC or BMI and metabolic syndrome was modified by gender or age group. Further studies will be needed to customize the national health screening and education programs.

Key words: metabolic syndrome, abdominal circumference, adiposity, universal health screening, risk factors

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Introduction

A sedentary lifestyle and overnutrition have led to an increase in number of individuals with obesity around the world, and as a result, cardiovascular diseases (CVDs) are increasingly burdening society (1-6). Therefore, it is crucial to detect high-risk individuals early and perform efficient intervention. The term "metabolic syndrome" was coined in 1999 to represent a unified condition in which the risk factors of atherosclerosis cluster on the basis of visceral adiposity due to overnutrition and physical inactivity (7). In Japan, universal health screening and education programs were launched in the early 2000s with the key objective of meas-

uring the abdominal circumference (AC) and assessing the number of metabolic risk components (i.e. blood pressure, lipid profiles, and glucose intolerance) to identify individuals with metabolic syndrome (8). These programs have made it simple to detect populations at high risk for CVD, since the measurement of AC is noninvasive and inexpensive. This has also allowed providers to closely monitor and intervene and to motivate participants to modify their lifestyle. Abdominal obesity is highly attributable to CVD among general populations, and focusing on AC is considered a good strategy for improving global health (9).

The current thresholds of AC and the body mass index (BMI) for classifying an individual with visceral adiposity were originally based on evidence concerning the correlation of the AC and BMI with the visceral fat area in approximately 1,200 Japanese individuals (10). The established cut-off value of visceral fat area (100 cm^2) is indicative of the risk of obesity-related disorders (i.e. high blood pressure, glucose intolerance, and dyslipidemia). The current unified thresholds of AC (85 cm for men and 90 cm for women) and BMI (25 kg/m^2), regardless of age group, have been introduced into universal health screenings across Japan in order to identify individuals with metabolic syndrome and implement education programs in each municipality. However, unified criteria to screen for metabolic syndrome might not necessarily work for everybody, especially the elderly. Indeed, making decisions based on false positives could lead to health issues, like malnutrition and sarcopenia, which are now major issues of public health in Japan's aging society.

The present study examined the relative association of BMI and AC with an increased risk of metabolic syndrome by age and gender in order to validate the current health screening and education programs for middle-aged and elderly people in Japan. We also evaluated suitable lifestyle modification factors to effectively implement educational programs for such individuals.

Materials and Methods

Participants

Study participants were corporate insurance beneficiaries of a major Japanese company who underwent annual health examinations between January 2004 and December 2014. The company provided us with anonymous health examination data of retired employees and their spouses, whose health records could be traced back to the periods of active service in the company. There were 24,698 individuals who underwent a health examination at least once during this period. We excluded participants without data on the AC, BMI, and other factors that were deemed necessary to identify metabolic syndrome (i.e. blood pressure, lipid profiles, and glucose intolerance) and ultimately included 22,953 individuals in the descriptive analyses and 11,390 in the multivariable analyses (Fig. 1).

We conducted the study in accordance with the guidelines of the Declaration of Helsinki.

Measurements

Physical measurements, including the height, weight, and AC, were made in the fasting state. BMI was calculated as the weight in kilograms divided by the square of the height in meters. AC was measured at the umbilical level in the standing position during light breathing. If the umbilicus was displaced due to marked fat accumulation, measurement was made at the level of the midpoint between the lower costal margin and iliac crest. BMI was classified into 3 categories: underweight (<18.5 kg/m^2), normal (18.5 to 25 kg/m^2), and obese (25 kg/m^2). Blood pressure (BP) was measured in the sitting position using an automatic sphygmomanometer. The biochemical measurements included measurements of total cholesterol (TC), triglyceride (TG), high density lipoprotein cholesterol (HDL-c), low density lipoprotein cholesterol (LDL-c), and fasting plasma glucose (FPG).

Education programs were designed based on the lifestyle information sought from questionnaires. Lifestyle was evaluated using self-administered questionnaires and included items regarding smoking, physical activity, eating habits, drinking habits and body weight change. Smoking was classified as follows: currently smoking (value = 1), and those who had never smoked or smoked in the past (value = 0). Items related to physical activity were classified as follows: regular exercise habits >30 minutes per day, daily physical activity >60 minutes per day, and walk faster than average speed. With respect to eating habits, questionnaires included the following items: eat faster than average, eat dinner two hours before going to bed, midnight snack at least three times a week, and skip breakfast. Responses for drinking habits were divided into four categories based on the amount of alcohol consumption (less than 20 g per day, 20 to 40 g per day, 40 to 60 g per day, and more than 60 g per day). Questionnaires also included the following items regarding body weight change: increase by more than 10 kg after 20 years of age and ±3kg change in the last 1 year.

Diagnostic criteria of metabolic syndrome in Japan

In 2005, the Japanese criteria for metabolic syndrome were established. In these criteria, AC is used as an index of visceral adiposity, and individuals with metabolic syndrome are defined as those who have visceral adiposity as demonstrated by an increased AC (≥ 85 cm for men and ≥ 90 cm for women) and ≥ 2 risk components. Risk components were defined as follows (11):

1) Abnormality in lipid profile:

Hypertriglyceridemia ≥ 150 mg/dL and/or Hypo-HDL-cholesterolemia <40 mg/dL

2) Abnormality in blood pressure control:

Systolic blood pressure (SBP) ≥ 130 mmHg and/or Diastolic blood pressure (DBP) ≥ 85 mmHg

3) Glucose intolerance:

Fasting hyperglycemia ≥ 110 mg/dL

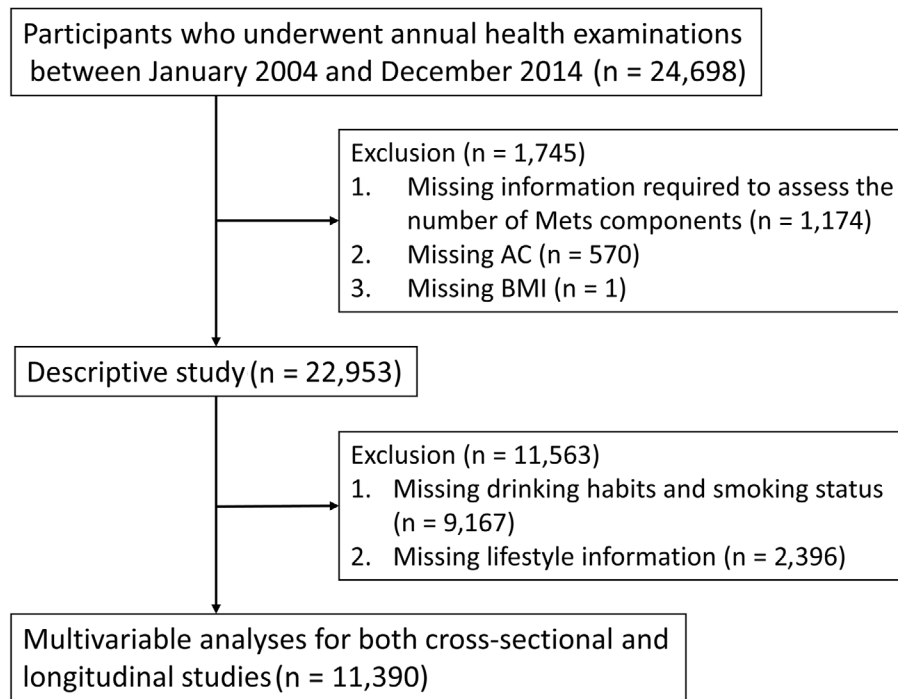We added individuals taking medication to each category,

Figure 1.   Flowchart of study participants.

regardless of the values of the parameters. Medication information was based on the self-administered questionnaires.

Study design

This was a retrospective cohort study in which we conducted two analyses. In the first part, we defined an outcome as having ≥ 2 risk components which we mentioned in the earlier section and examined the cross-sectional association of the AC and BMI with the outcome. In the second part, we assessed the effects of time-updated lifestyle information on metabolic traits (i.e. AC, BMI, SBP, DBP, FPG, HDL-c, LDL-c, and TG) and examined the longitudinal association between metabolic traits and lifestyle information.

Statistical analyses

We set the baseline as the first health examination record for each participant during the study period between 2004 and 2014 and compared the characteristics between men and women. The mean ± standard deviation (SD) and median [interquartile range (IQR)] were calculated for normally and non-normally distributed continuous variables, respectively. Normal probability plots and histograms were employed to judge whether or not the data followed normal distributions. Differences in categorical, normal, and non-normally distributed continuous variables between the two cohorts were assessed using either Fisher's exact test or the chi-squared test, Student's t-test, and Wilcoxon's rank-sum test, respectively.

We examined the age and gender group-specific cut-offs for the AC and BMI, stratifying both men and women into the following 3 categories: <55, 55 to 65, and >65 years old. We defined the outcome as having ≥ 2 risk components and employed logistic regression models to examine optimal

cut-off values that maximize the Youden index for each model. We then calculated sensitivity and specificity in each group.

We employed a multivariable logistic regression analysis to examine the association between the outcome and AC or BMI, adjusted for the age, gender (model 1); factors in model 1, current smoking status, and drinking habits (model 2); and factors in model 2, body weight (BW) increase by more than 10 kg after 20 years of age, regular exercise habits >30 min/day, daily physical activity >60 min/day, fast walking speed, ±3kg change in the last year, eating faster, eating dinner 2 hours before going to bed, midnight snacking, and skipping breakfast (model 3). In the final model, we considered a variance inflation factor >5 to indicate potential multicollinearity and omitted variables from the model. We set the AC or BMI as the main exposure of interest and having ≥ 2 risk components as the outcome. Interactions between the AC or BMI and gender or age category were evaluated. We also used multinomial logistic regression models to evaluate the probability of the number of risk components subjects had at the baseline to be from 0 to 3.

We employed linear mixed effects models to examine the association between metabolic traits and lifestyle information, adjusted for age, gender, smoking habit, and drinking habit. The outcome variables were metabolic traits (i.e. AC, BMI, SBP, DBP, FPG, HDL-c, LDL-c, and TG). All data were treated as fixed effects, and the within-subject covariance was unstructured. $p < 0.05$ was considered statistically significant.

The data were analyzed using the Stata/MP 16.0 software program for Windows (Stata, College Station, USA). "Marginsplot" syntax in Stata was used to visually show the

Table 1.   Baseline Characteristics.

Variables	N	All	Male	Female
Number of participants	22,953		12,405	10,548
Age, years	22,953	62.7±4.6	63.9±4.5	61.3±4.2
BMI, kg/m^2	22,953	22.7±3.0	23.2±2.7	22.1±3.2
-18.5		1,413 (6.2)	371 (3.0)	1,042 (9.9)
18.5-25		16,876 (73.5)	9,074 (73.1)	7,802 (74.0)
25-		4,664 (20.3)	2,960 (23.9)	1,704 (16.1)
AC, cm	22,953	82.4±8.3	83.9±7.6	80.6±8.8
Systolic blood pressure, mmHg	22,953	127±17	129±17	125±17
Diastolic blood pressure, mmHg	22,953	78±11	80±11	75±11
Total cholesterol, mg/dL	19,030	217.1±34.2	206.8±32.1	226.4±33.3
Low density lipoprotein cholesterol, mg/dL	22,672	129.3±30.6	124.4±29.6	135.3±30.7
High density lipoprotein cholesterol, mg/dL	22,953	61.0 [52.0-73.0]	57.0 [48.0-67.0]	67.0 [57.0-78.0]
Triglyceride, mg/dL	22,953	95.0 [69.0-131.0]	104.0 [76.0-144.0]	86.0 [64.0-117.0]
Fasting plasma glucose, mg/dL	22,953	97.0 [90.0-105.0]	100.0 [93.0-109.0]	93.0 [88.0-100.0]
Lifestyle / habits, n (%)				
Current smoking	22,873	3,330 (14.6)	2,971 (24.1)	359 (3.4)
Alcohol intake	13,807			
-20g/day		7,109 (51.5)	3,844 (39.0)	3,265 (82.9)
20-40g/day		4,403 (31.9)	3,837 (38.9)	566 (14.4)
40-60g/day		1,721 (12.5)	1,638 (16.6)	83 (2.1)
60g/day-		574 (4.2)	549 (5.6)	25 (0.6)
More than 10 kg increase after 20 years of age	19,173	5,901 (30.8)	3,418 (37.7)	2,483 (24.6)
Regular exercise habits>30 min/day	21,935	9,260 (42.2)	4,941 (42.2)	4,319 (42.2)
Daily physical activity>60 min/day	21,926	10,573 (48.2)	5,639 (48.2)	4,934 (48.2)
Fast walk speed	19,186	10,729 (55.9)	5,396 (59.2)	5,333 (52.9)
±3 kg change in the last one year	19,230	2,961 (15.4)	1,403 (15.4)	1,558 (15.4)
Eat faster	21,933	5,442 (24.8)	2,702 (23.1)	2,740 (26.8)
Eat dinner 2 hours before going to bed	21,958	3,392 (15.4)	2,551 (21.8)	841 (8.2)
Midnight snack	19,250	1,814 (9.4)	663 (7.3)	1,151 (11.4)
Skip breakfast	21,901	1,076 (4.9)	682 (5.8)	394 (3.8)
Medication, n (%)				
Medication for dyslipidemia	22,953	3,224 (14.0)	1,522 (12.3)	1,702 (16.1)
Medication for hypertension	22,953	5,645 (24.6)	3,623 (29.2)	2,022 (19.2)
Medication for diabetes	22,953	1,279 (5.6)	921 (7.4)	358 (3.4)
Follow up period, years	22,953	3.0 [2.0-4.0]	3.0 [1.0-4.0]	4.0 [2.0-4.0]

BMI: body mass index, AC: abdominal circumference

Continuous data represent mean±standard deviation or medians (1st quartile, 3rd quartile) as appropriate. Categorical data indicate n values (%).

trends in the probability of having ≥ 2 risk components across levels of AC and BMI stratified by age category or gender in the logistic regression models. All covariates were fixed at their means in this analysis.

Results

Baseline characteristics

Baseline characteristics were summarized in Table 1. In brief, the mean age was 62.7±4.6 years old, and men accounted for 54% of the total participants. Both the SBP and DBP were higher in men than in women, and the proportion of individuals under medication was also higher in men than in women. Both the LDL and HDL cholesterol levels were higher in women than in men, and the proportion of indi-

viduals under medication was also higher in women than in men. Although the number of women respondents to the question on alcohol consumption was only 3,939 (37%), the proportion consuming ≥ 60 g/day alcohol was 5.6% among men and 0.6% among women. Current smokers accounted for 24.1% and 3.4% of men and women, respectively. Individuals who habitually ate midnight snacks accounted for 7.3% of men and 11.4% of women. The data from the National Health and Nutrition Survey (2018) (12) showed that the proportion of current smokers was 29.1% in men and 8.1% in women, and 3.7% of men and 11.2% of women were found to be underweight (BMI <18.5 kg/m^2), while the prevalence of obesity (BMI >25 kg/m^2) was 32.2% in men and 21.9% in women. The mean SBP was 134.7 mmHg in men and 127.9 mmHg in women. All of these values were better in the study population than in the general population.

Table 2.   Number of Metabolic Syndrome Risk Components in Study Participants.

Number of risk components	Components	Number (%)
0	None of the three components	6,924 (30.2)
1	High Blood pressure	6,443 (28.1)
	Dyslipidemia	1,914 (8.3)
	Glucose intolerance	818 (3.6)
2	High blood pressure+dyslipidemia	3,178 (13.8)
	High blood pressure+glucose intolerance	1,758 (7.7)
	Dyslipidemia+glucose intolerance	431 (1.9)
3	All three components	1,487 (6.5)
Total		22,953

Table 3.   Age and Gender Group-specific Cutoffs of AC and BMI.

	Male				Female			
	AUC	Cutoff (cm)	Sensitivity (%)	Specificity (%)	AUC	Cutoff (cm)	Sensitivity (%)	Specificity (%)
AC (cm)								
Overall	0.65	83.8	64	58	0.67	80.8	67	58
<55 years	0.68	83.8	75	55	0.72	80.3	74	61
55-65 years	0.65	83.8	67	56	0.67	80.8	66	58
65≥ years	0.64	84.9	53	67	0.64	83.7	54	67
BMI (kg/m^2)								
Overall	0.65	23.1	63	59	0.67	22.1	64	62
<55 years	0.69	22.8	82	53	0.74	22.8	71	69
55-65 years	0.66	23.1	67	57	0.68	21.9	67	59
65≥ years	0.63	23.1	58	61	0.65	22.1	63	60

AC: abdominal circumference, BMI: body mass index, AUC: area under curve

Table 4.   Association of BMI and Abdominal Circumferences with Having Two or More Risk Components of Metabolic Syndrome (n=11,390).

	Model 1		Model 2		Model 3	
	OR (95% CI)	p value	OR (95% CI)	p value	OR (95% CI)	p value
AC (per 5 cm)	1.22 (1.16-1.28)	<0.001	1.21 (1.15-1.27)	<0.001	1.17 (1.12-1.24)	<0.001
BMI (per 1 kg/m^2)	1.11 (1.08-1.15)	<0.001	1.12 (1.09-1.15)	<0.001	1.10 (1.07-1.13)	<0.001

BMI: body mass index, AC: abdominal circumference, OR: odds ratio

Model 1: age and genders

Model 2: Model 1, current smoking status, and drinking habits

Model 3: Model 2, more than 10 kg of BW increase after 20 years of age, regular exercise habits>30 min/day, daily physical activity > 60 min/day, fast walk speed, ± 3 kg change in the last one year, eat faster, eat dinner 2 hours before going to bed, midnight snack, and skip breakfast

The number of participants in each combination of risk components are summarized in Table 2. Of the 22,953 participants, 6,924 had no metabolic syndrome risk components, 9,175 had 1 of the 3 risk components, and 6,854 had ≥ 2 risk components.

Age and gender group-specific optimal cut-off values for having ≥ 2 metabolic components

Table 3 shows the optimal cut-offs of the AC and BMI for having ≥ 2 metabolic components in different age- and gender-groups. The overall cut-off for men was 83.8 cm for AC (with a sensitivity of 64% and a specificity of 58%), while that for women was 80.8 cm (with a sensitivity of 67% and a specificity of 58%). However, for men and women who were >65 years old, the cut-offs were 84.9 cm and 83.7 cm, respectively, with a lower sensitivity (53% for men and 54% for women.)

Cross-sectional association between AC or BMI and having ≥ 2 metabolic components

Table 4 shows the association between the exposures and the outcome. In the age- and gender-adjusted model, the odds ratio (OR) of AC per 5 cm was 1.22 [95% confidence interval (CI), 1.16-1.28], and that of BMI per 1 kg/cm^2 was
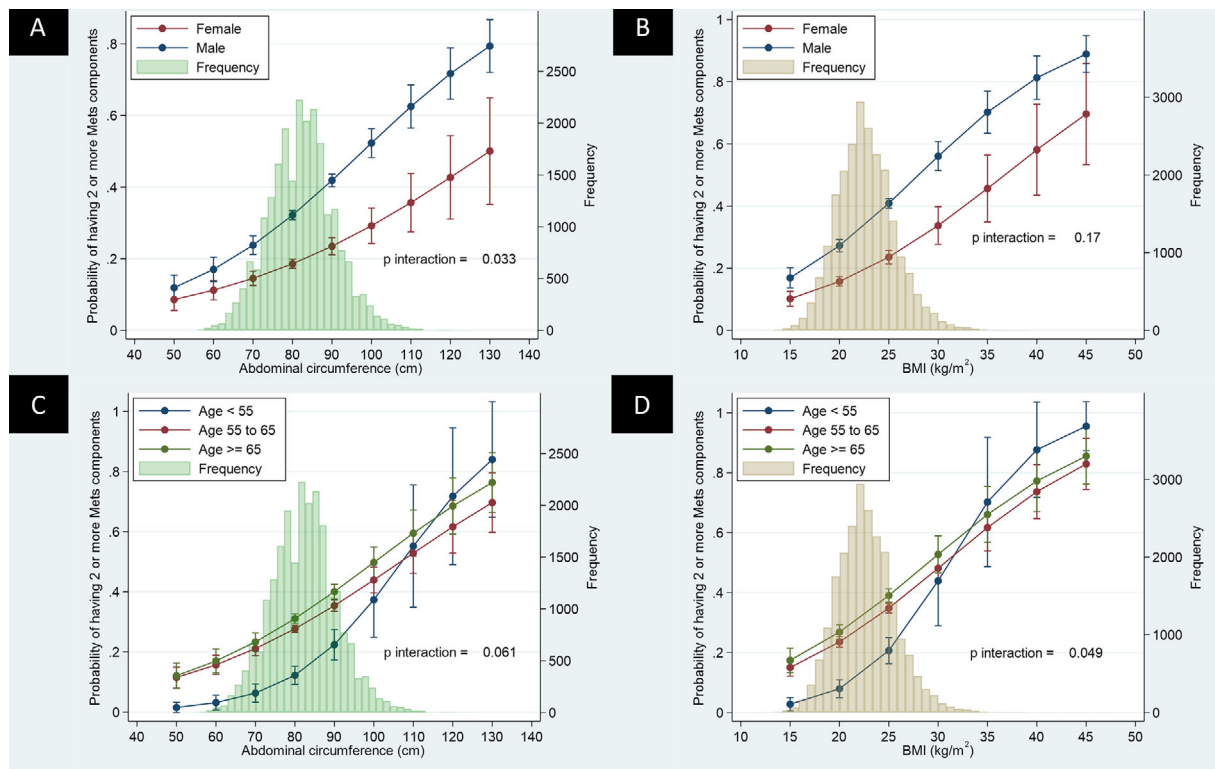
Figure 2. Association of BMI or abdominal circumference with having ≥2 Mets components stratified by gender or age. A: The interaction between abdominal circumference and gender was significantly associated with the outcome (p=0.033). B: The interaction between BMI and gender was not significantly associated with the outcome (p=0.17). C: The interaction between abdominal circumference and age group was not significantly associated with the outcome (p=0.061). D: The interaction between BMI and age group was significantly associated with the outcome (p=0.049). Mets: metabolic syndrome, BMI: body mass index

1.11 (95% CI, 1.08-1.15). In the final model, the OR of AC per 5 cm was 1.17 (95% CI, 1.12-1.24), and that of BMI per 1 kg/cm² was 1.10 (95% CI, 1.07-1.13), adjusted for the current smoking status, drinking habit, BW increase by more than 10 kg after 20 years of age, regular exercise habits >30 min/day, daily physical activity >60 min/day, fast walking speed, ±3kg change in the last year, eating faster, eating dinner 2 hours before going to bed, midnight snacking, and skipping breakfast. No potential multicollinearity was found in the multivariable models. Therefore, no variables were omitted from the models.

Metabolic syndrome was defined as having visceral adiposity demonstrated by an increased AC (≥ 85 cm for men and ≥ 90 cm for women) and ≥ 2 metabolic components. We illustrated the validity of having ≥ 2 metabolic components in Supplementary material 1. As the AC and BMI increase, the probability of having ≥ 2 metabolic components increases, whereas the probability of having none or 1 metabolic component decreases.

Fig. 2 shows the effect modification by gender and age group, adjusted for age, gender, smoking status, and drinking habits. There was a significant interaction between the AC and gender (p = 0.033), while no significant interaction was noted between BMI and gender (p = 0.17). Although

the interaction between AC and age group was not significant (p = 0.061), there was a significant interaction between BMI and age group (p = 0.049).

Longitudinal association between lifestyle information and metabolic traits

Fig. 3 shows forest plots of the association between metabolic traits (i.e. AC and BMI) and lifestyle factors. Current smoking was associated with a 0.73 (0.56-0.90)-cm increase in the AC and a 0.41 (0.37-0.44)-kg/m² increase in BMI. Alcohol consumption was associated with a 0.33 (0.23-0.42)-cm increase in AC for 20-40 g/day, 0.57 (0.42-0.71)-cm increase for 40-60 g/day, 0.52 (0.30-0.75)-cm increase for <60 g/day, and 0.090 (0.066-0.11)-kg/m² increase in BMI for 20-40 g/day, 0.14 (0.11-0.18)-kg/m² increase for 40-60 g/day, and a 0.12 (0.074-0.17) -kg/m² increase for >60 g/day compared with <20 g/day. A BW increase by >10 kg after 20 years of age was associated with a 3.0 (2.9-3.2)-cm increase in AC and 0.65 (0.63-0.68)-kg/m² increase in BMI. Physical activity was associated with a decrease in both the AC and BMI: a regular exercise habit of >30 minutes a day was associated with a 0.20 (0.12-0.28)-cm decrease in AC and 0.058 (0.038-0.078)-kg/m² decrease in BMI, daily physical activity more than 60 minutes a day was associated with a
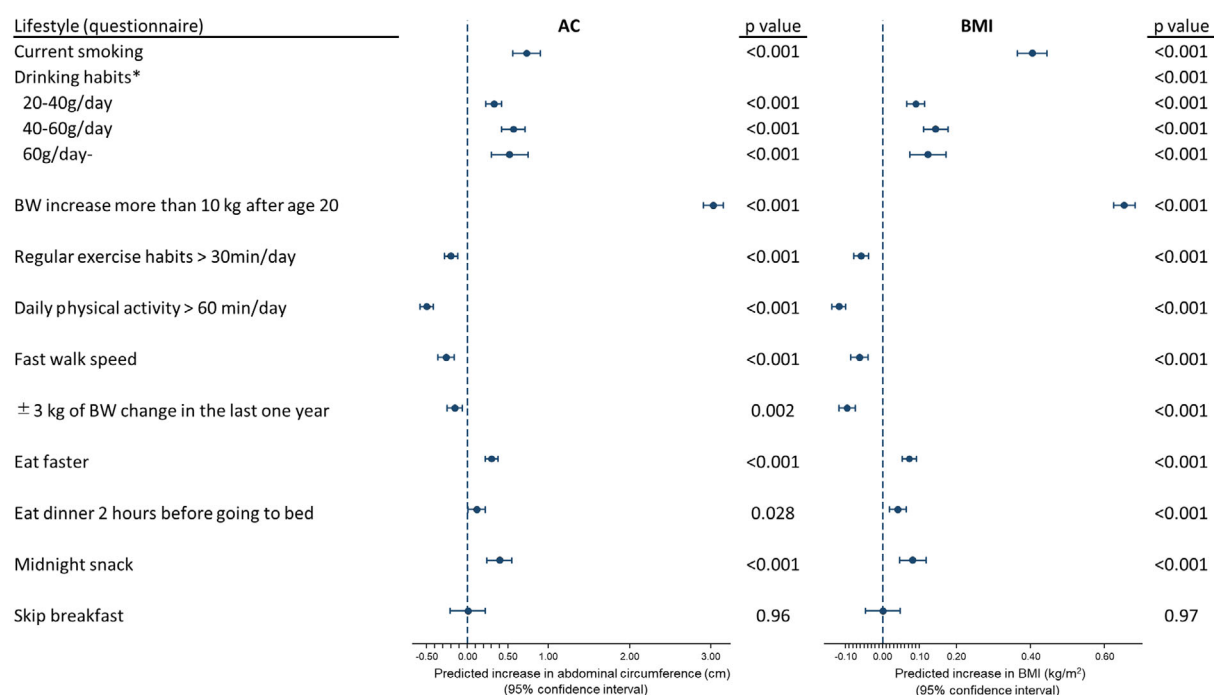
Figure 3. **Predicted changes in BMI and abdominal circumference by lifestyle factors. *The reference category is <20 g alcohol consumption per day. BW: body weight, AC: abdominal circumference, BMI: body mass index**

0.50 (0.42-0.58)-cm decrease in AC and 0.12 (0.10-0.14)-kg/m^2 decrease in BMI, and walking faster than the average person was associated with a 0.26 (0.16-0.36)-cm decrease in AC and 0.062 (0.039-0.086)-kg/m^2 decrease in BMI. Unhealthy eating habits, except for skipping breakfast, were associated with an increase in both AC and BMI: eating faster than the average person was associated with a 0.30 (0.22-0.38)-cm increase in AC and 0.072 (0.052-0.091)-kg/m^2 increase in BMI, eating dinner ≤ 2 hours before going to bed was associated with a 0.12 (0.010-0.22)-cm increase in AC and 0.041 (0.018-0.064)-kg/m^2 increase in BMI, and eating a midnight snack was associated with a 0.40 (0.24-0.55)-cm increase in AC and 0.081 (0.045-0.12)-kg/m^2 increase in BMI.

Other metabolic traits (i.e., SBP, DBP, FPG, HDL-c, LDL-c, and TG) were associated with lifestyle factors. The smoking status was associated with an increase in the SBP, DBP, FPG, HDL-c, and LDL-c and a decrease in the TG. Drinking habits were associated with an increase in the SBP, DBP, FPG, HDL-c, and TG and a decrease in the LDL-c. An increase in the BW after 20 years of age was associated with an increase in the SBP, DBP, FPG, LDL-c, and TG and a decrease in the HDL-c. Physical activity was associated with a decrease in the FPG, LDL-c, and TG and a decrease in the HDL-c. Eating habits did not show constant results (See details in Supplementary material 2).

Discussion

In the present study, we clearly demonstrated that higher values for BMI or AC were associated with having ≥ 2 risk

components of metabolic syndrome, and these associations were altered by age and gender. We also showed the longitudinal association of lifestyle information with BMI and AC.

This study was unique because the corporate insurance program included in this study covers the elderly up to 75 years old. In most other corporate health insurance programs in Japan, individuals often lose their beneficiary status around the age of 60 to 65. However, in this cohort, participants belonged to the same corporate insurance until they moved to another health insurance provider or reached 75 years old, which prompts mandatory transition to the national health insurance system. This allowed us to obtain data from not only middle-aged individuals but also individuals over 65 years old, which is the currently prevailing mandatory retirement age in Japan. Furthermore, enriched self-administered questionnaires provided us with various kinds of lifestyle information, including data on smoking habits, alcohol consumption, eating habits, physical activity, and changes in body weight. Although many previous occupational health studies in Japan were not gender balanced (13-16), our cohort contained a substantial proportion of women. Furthermore, we performed not only cross-sectional but also longitudinal analyses. This allowed us to examine the association between time-updated lifestyle information and metabolic traits and to focus more on changes in BMI or AC rather than uniform cut-off values (AC, 85 cm in men and 90 cm in women and BMI, 25 kg/m^2 in both genders) based on the healthcare policy in Japan.

We showed the seamless and monotonic association between AC or BMI and having ≥ 2 risk components of meta-

bolic syndrome. Current health screening strategies based on unified cut-off values differ between genders and do not seem to be the optimum approach. In particular, the interaction between AC and gender was significant, perhaps because abdominal muscular tension differs between men and women. This cannot be solved just by changing the cut-offs by gender; a new health promotion strategy taking into account both age and gender differences needs to be developed.

Similarly, the association between AC and metabolic syndrome differed across age groups, although it was not statistically significant. For individuals under 55 years old, the association was steeper than in any other age group. As people get older or more physically inactive, abdominal muscular tension gradually decreases. Therefore, since AC represents not only visceral adiposity but also reduced muscle or frailty, an increased AC might not always be associated with risk components of metabolic syndrome. BMI is more ambiguous, as its components comprise water, muscle, fat, and other tissue. As people age, the body composition changes to include more fat and less muscle. The presence of more muscle may reflect physical activity, which is protective against metabolic syndrome. Therefore, simple anthropometric obesity categorization does not necessarily contribute to the precise risk stratification, let alone "obesity paradox" issues (17-21). In a large population-based study, the association between BMI and CVDs or other serious health status was modified by age group (22). Thus, these results suggest that the older an individual is, the less impact BMI has on poor health conditions.

We also identified suitable lifestyle modification factors, such as regular exercise habits and the avoidance of eating quickly or midnight snacking, which may help reduce AC or BMI and prevent an individual from having more metabolic risk components. Even though the impact of AC or BMI differed across age and gender groups, these lifestyle modifications may help reduce the number of metabolic risk components.

Several limitations associated with the present study warrant mention. First, we were unable to obtain clinical information, including data on events, such as the development of CVDs, hospital admission, or death. Thus, it was challenging to fully elucidate the clinical relevance of AC and BMI. Second, there may have been some selection bias, since individuals who already had some clinical conditions might not have participated in the universal health screening programs. Thus, relatively healthy individuals might have been more likely to be enrolled in this study than others. However, from the perspective of public health, focusing more on those relatively healthy individuals should be the scope of the universal health screening and education programs to prevent them from developing CVD and other serious medical conditions. Selection bias can manifest in the form of a collider bias, wherein undergoing health examinations could be a collider between healthy/unhealthy behavior and the outcomes. Before mandatory retirement, people are more likely to undergo health examinations because it is their duty to do so as an employee. However, after retirement, people might not undergo health examinations as often as they used to. Thus, health literacy might differ across age groups.

In conclusion, we clearly demonstrated the seamless and monotonic association between AC or BMI and having ≥ 2 metabolic risk components; the association with AC was modified by gender, and the association with BMI was modified by age group. We also identified suitable lifestyle modification factors to reduce AC or BMI. These results raise important questions regarding the national health screening and education programs from the perspective of precision medicine. Further studies are needed to examine the real-world implementation of age- and gender-specific intervention and education programs.

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